Transducers

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Scheme of evaluation and Solutions

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Scheme of Evaluation

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	Value of R -- 1M
	Limiting error in R -- 1M
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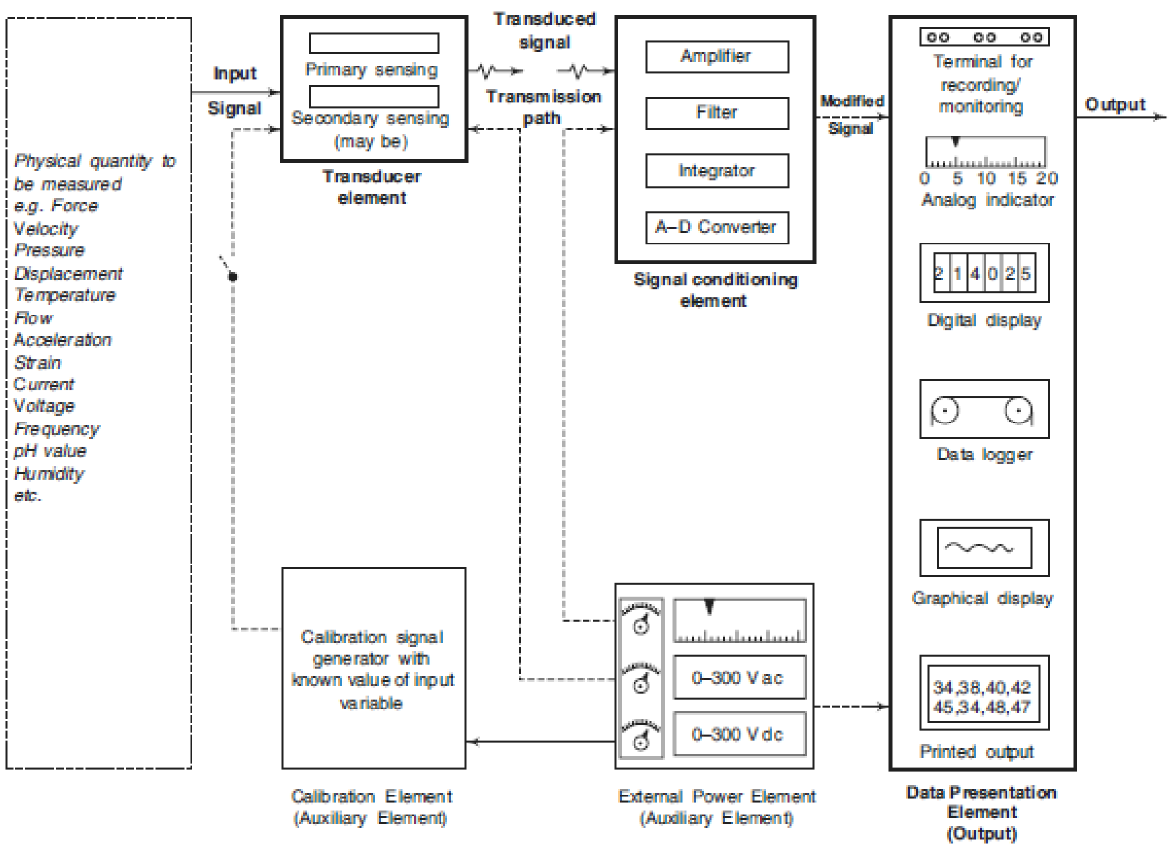
Answers

1 (a) The limits of deviation of a quantity from the specified value are known as limiting errors.
(b) It is the smallest change in the measured value to which the transducer responds.
(c) Steady state gain, damping factor and undamped natural frequency.
(d) Active transducers does not require external power whereas passive transducers require external power.
(e) Ratio of Change in length to original length.
(f) Variation of mutual inductance between the primary and secondary coils with displacement of the core.
(g) displacement measurement, level measurement
(h) Quartz, Rochelle Salt, Barium titanate.
(i) The sensors having decision making and communication logic added to the basic sensors, are called smart sensors
(j) The working principle is variation of resistance with temperature

2(a)

Block Diagram of a measurement system :



The generalised ' Measurement system' consists of the following
1. Basic Functional Elements, and
2.Auxiliary Functional elements

Basic Functional Elements :
(i)Transducer Element : It senses and converts the desired input to a more convenient and practical form to be handled by the measurement system.
(ii)Signal Conditioning : It manipulates or processes the output of the transducer in a suitable form.

(iii)Data presentation element : It gives the information about the measurand or measured variable in the quantitative form.

Auxiliary Functional elements :
(i) Calibration Element : It is to provide a built in calibration facility
(ii)External power element : It is to facilitate the working of one or more of the elements like the transducer element, the signal conditioning element, the data processing element or the feedback element.
(iii)Feedback Element : It is to control the variation of physical quantity that is being measured. In addition, the feedback element is provided in the null seeking potentiometer or Wheatstone bridge devices to make them automatic or self balancing.
(iv)Microprocessor Element : It is to facilitate the manipulation of data for the purpose of simplifying or accelerating the data interpretation. It is always used in conjunction with analog to digital converter which is incorporated in the signal conditioning element.

2(b)
The following are the data for a Hay's ac bridge: R1 = 1000 Ω ± 1 part in 10000,
R2 = 16800 Ω ± 1 part in 10000, R3 = 833 Ω ± 0.25 Ω, C = 1.43 ± 0.001μF. If the frequency of the supply voltage is 50 ± 0.1Hz and the formulae for L and R in the balanced condition of the bridge are

$$L = \frac{CR_1R_2}{1+\omega^2C^2R_3{}^2} \qquad R = \frac{R_1R_2R3C^2\omega^2}{1+\omega^2C^2R_3{}^2}$$

determine the values of L and R of the coil and their limits of error.

Solution :

Given $\frac{\partial R_1}{R_1} = \frac{\partial R_2}{R_2}$ = 1 part in 10000 = 0.01%

$$\frac{\partial R_3}{R_3} = \frac{0.25}{833} \times 100\% = 0.03\%$$

$$\frac{\partial C}{C} = \frac{0.001}{1.43} \times 100\% = 0.07\% \qquad \frac{\partial \omega}{\omega} = \frac{0.1}{50} \times 100\% = 0.2\%$$

Thus,

$$L = \frac{CR_1R_2}{1+\omega^2C^2R_3{}^2}$$

$$= \frac{(1.43\times10^{-6})(1000)(16800)}{1+(100\pi)^2(1.43\times10^{-6})^2(833)^2} = 21.1\text{H}$$

$$\frac{\partial L}{L} = 3\frac{\partial C}{C} + \frac{\partial R_1}{R_1} + \frac{\partial R_2}{R_2} + 2\frac{\partial R_3}{R_3} + 2\frac{\partial \omega}{\omega}$$

= [(3 ×0.07) + 0.01 + 0.01 + (2× 0.03) + (2× 0.2)]% = 0.69%
Therefore L = 21 H ± 0.69%

$$R = \frac{R_1R_2R3C^2\omega^2}{1+\omega^2C^2R_3{}^2}$$

$$= \frac{(1000)(16800)(833)(1.43\times10^{-6})^2(100\pi)^2}{1+(100\pi)^2(1.43\times10^{-6})^2(833)^2} = 2477\ \Omega$$

$$\frac{\partial R}{R} = \frac{\partial R_1}{R_1} + \frac{\partial R_2}{R_2} + 3\frac{\partial R_3}{R_3} + 4\frac{\partial C}{C} + 4\frac{\partial \omega}{\omega}$$

= [0.01 + 0.01 + (3 × 0.03) + (4 × 0.07) + (4 × 0.2)] = 1.19%
Therefore R = 2477 Ω ± 1.19%

3(a)

Static Characteristics of Instruments :

Accuracy : Accuracy of a measuring system is defined as the closeness of the instrument output to the true value of the measured quantity.

Accuracy of the instrument mainly depends on the inherent limitations of the instrument as well as the shortcomings in the measuring process.

The accuracy of an instrument depends on the various systemetic errors involved in the measurement process.

The accuracy of the instruments can be specified in either of the following forms:

1. Percentage of true value

$$= \frac{\text{measured value} - \text{true value}}{\text{true value}} \times 100$$

2. Percentage of full-scale deflection

$$= \frac{\text{measured value} - \text{true value}}{\text{maximum scale value}} \times 100$$

Precision :

Precision is defined as the ability of the instrument to reproduce a certain set of readings within a given accuracy.

Precision of an instrument is in fact, dependent on repeatability. Repeatability can be difined as the ability of the instrument to reproduce a group of measurements of the same measured quantity, made by the same observer, using the same instrument, under the same conditions.

Precision of the instrument depends on the factors that cause random or accidental errors.

Accuracy Vs Precision :

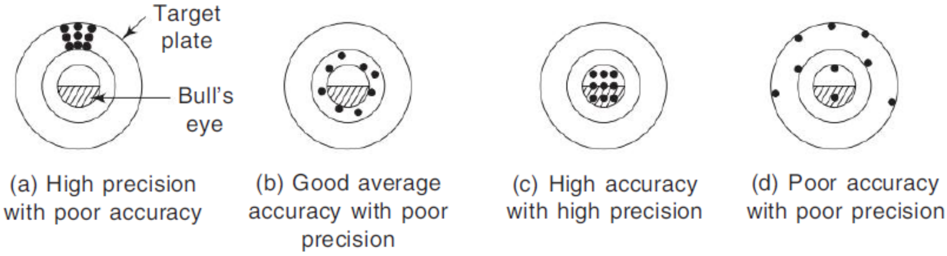


Illustration of degree of accuracy and precision in a typical target shooting experiment

Resolution (or Discrimination) :

It is defined as the smallest increment in the measured value that can be detected with certainty by the instrument.

Threshold :

It is defined as the minimum value of the input below which no output can be detected.

Both threshold and resolution can either be specified as absolute quantities in terms of input units or as percentage of full scale deflection.

Both threshold and resolution are not zero because of various factors like

- friction between moving parts
- play or looseness in joints(more correctly termed as backlash)
- inertia of the moving parts
- length of the scale
- spacings of graduations

- size of the pointer
- parallax effect, etc.

Static sensitivity :

Static sensitivity (also termed as scale factor or gain) of the instrument is determined from the result of static calibration.

Static sensitivity (also termed as scale factor or gain) of the instrument is defined as the ratio of the magnitude of response (output signal) to the magnitude of the quantity being measured(input signal), i.e.

$$\text{Static sensitivity,} \qquad K = \frac{\text{change of output signal}}{\text{change in input signal}}$$

$$= \frac{\Delta q_o}{\Delta q_i}$$

where q_o and q_i are the values of the output and input signals, respectively.

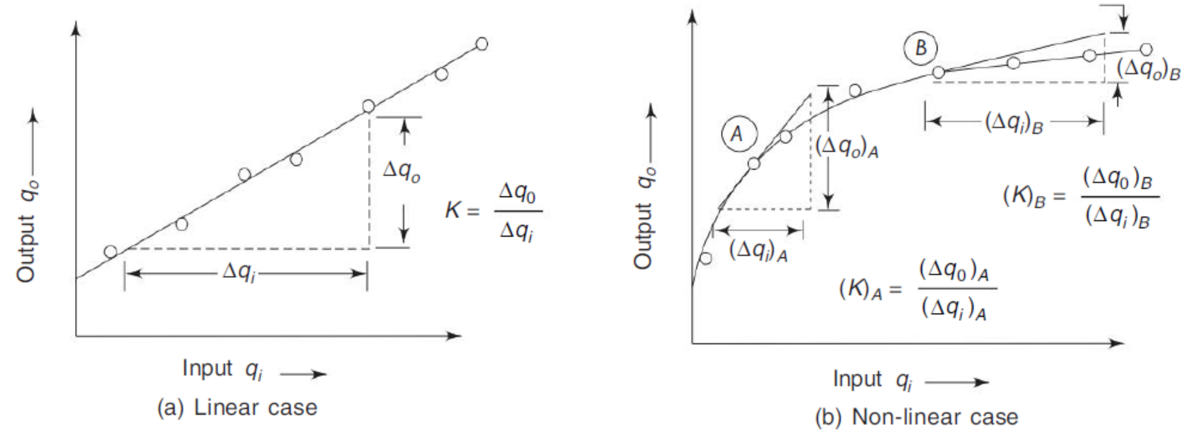


Fig: Static sensitivity of linear and non-linear instruments

Linearity :

A linear indicating scale is one of the most desirable features of any instrument. Therefore, manufactures of instruments always attempt to design their instruments so that the output is a linear function of the input.

However, linearity is never completely achieved and the deviations from the ideal are termed as linearity tolerances.

In commercial instruments, the maximum departure from linearity is often specified in one of the following ways.

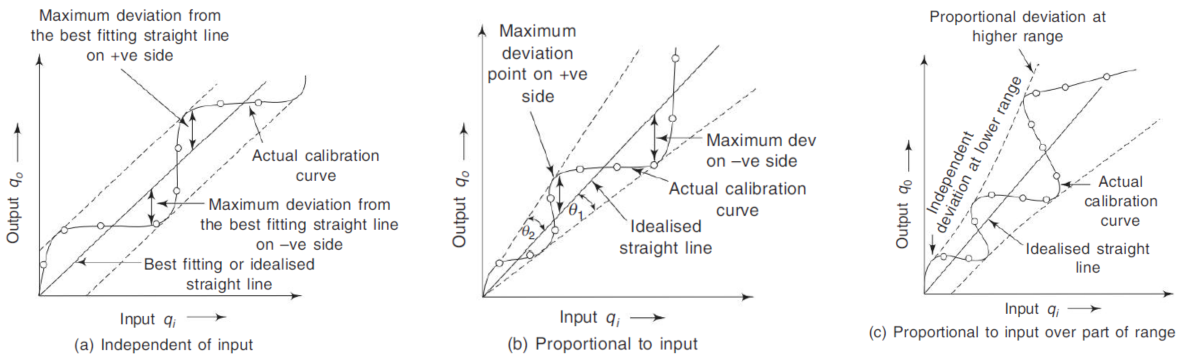


Fig : Typical specifications of non-linearity

Range and Span :

The range of the instrument is specified by the lower and upper limits in which it is designed to operate for measuring, indicating or recording the measured variable.

The algebraic difference between the upper and lower range values is termed as span of the instrument.

The over-range (or overload capacity) of the instrument is the maximum value of measurand that can be applied to the instrument without causing a perceptible change i.e., a change beyond specified tolerances.

Further, the recovery time of the instrument is the amount of time elapsed after the removal of the overload conditions before it performs again within the specified tolerances.

Hysteresis :

It is defined as the magnitude of error caused in the output for a given value of input, when this value is approached from opposite directions, i.e. from ascending order and then descending order.

Hysteresis is caused by backlash, elastic deformations, magnetic characteristics, but is mainly caused due to frictional effects.

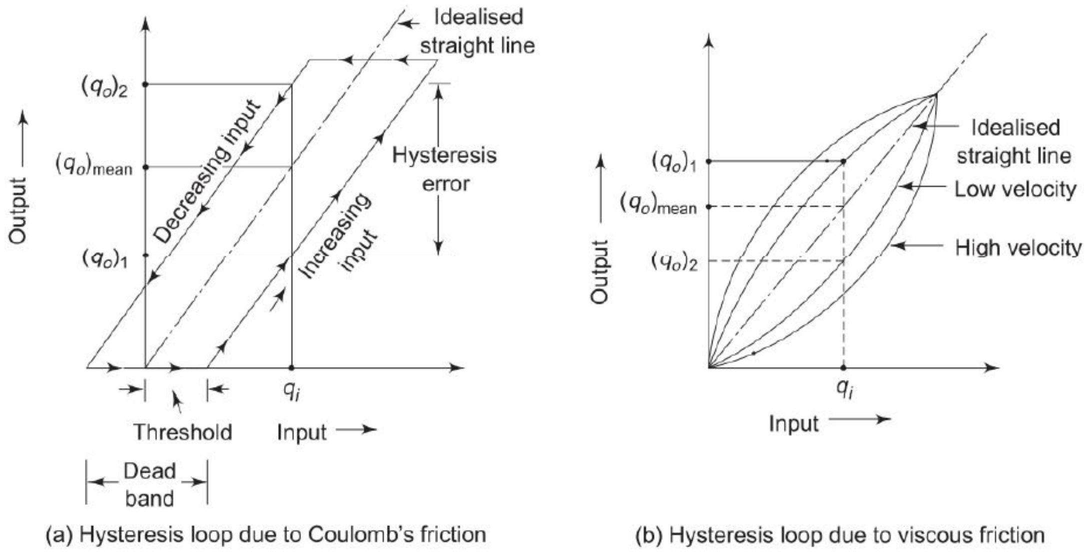


Fig : Typical out-input curves showing hysteresis effects

Hysteresis effects are best eliminated by taking the observations both for ascending and descending values of input and then taking the arithmetic mean.

Dead Band:

It is defined as the largest change of the measurand to which the instrument does not respond.

For example, in the output-input curve with hysteresis effect due to Coulomb's friction, the extent of dead band is shown. In such a case, it is approximately twice the threshold value.

Backlash :

It si defined as the maximum distance or angle through which any part of the mechanical system may be moved in one direction without causing motion of the next part.

The output-input characteristics of an instrument system with backlash error is similar to hysteresis loop due to Coulomb's friction.

Backlash error can be minimised if the components are made to very close tolerances.

Drift :

It is defined as the variation of output for a given input caused due to change in the sensitivity of the instrument due to certain interfering inputs like temperature changes, component instabilities, etc.

3(b)

Reading, x	d = x - $\bar{x}$
12.8	0.15
12.2	-0.45
12.5	-0.15
13.1	0.45
12.9	0.25
12.4	-0.25

(a)Arithmetic mean = sum of readings/ no of readings
= 75.9/6
= 12.65 mA
(b) deviation from the mean d = x - $\bar{x}$, which is tabulated above
(c) Average deviation = sum of magnitudes of deviation/ no of readings
= 1.7/6
= 0.2833 mA

4(a)
Derivation for gauge factor of a strain gauge :

Gauge factor is defined as the unit change in resistance per unit change in length and is expressed as

$$G = \frac{(\Delta R/R)}{(\Delta L/L)}$$

where G = Gauge factor or sensitivity
R = gauge wire resistance
ΔR = change in gauge wire resistance
L = length of the wire in the unstressed condition
The term ΔL/L in the denominator of the above equation is the strain σ
$\sigma = \frac{\Delta L}{L}$, strain in the longitudinal direction

The resistance of a metal wire is given by

$$R = \frac{\rho L}{A}$$

where ρ = resistivity or specific resistance of the wire
L = length of the wire
A = cross-section area of the wire
From the above equation

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - \frac{\Delta A}{A} ;$$

we have $A = \frac{\pi D^2}{4}$ where D = diameter of the wire

$$\frac{dA}{A} = \frac{\frac{2\pi D}{4}\Delta D}{\frac{\pi D^2}{4}}$$

$$= \frac{2\Delta D}{D}$$

Now

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - \frac{2\Delta D}{D}$$

Poisson's ratio is given by

$$\gamma = \frac{lateral\ strain}{longitudinal\ strain}$$

$$= \frac{-\frac{\Delta D}{D}}{\frac{\Delta L}{L}}$$

Now the above equation can be written as

$$\frac{\Delta R}{R} = \frac{\Delta \rho}{\rho} + \frac{\Delta L}{L} - 2\,\frac{-\gamma \Delta L}{L}$$
$$= \frac{\Delta \rho}{\rho} + (1 + 2\gamma)\frac{\Delta L}{L}$$

Gauge factor is defined by

$$G = \frac{(\Delta R / \Delta R)}{(\Delta L / L)} = 1 + 2\gamma + \frac{(\Delta \rho / \rho)}{(\Delta L / L)}$$
$$= 1 + 2\gamma + \frac{\Delta \rho}{\rho \varepsilon} \quad \text{where } \varepsilon = \frac{\Delta L}{L}$$

4(b)

$$G = \frac{(\Delta R / \Delta R)}{(\Delta L / L)}$$
$$2.5 = \frac{(0.7/280)}{(\Delta L / L)}$$
$$\left(\frac{\Delta L}{L}\right) = 0.001$$

$$\Delta L = 0.3\, mm$$
$$G = 1 + 2\gamma$$
$$2.5 = 1 + 2\gamma$$
$$\gamma = 0.75$$
$$\gamma = \frac{(\Delta d / d)}{(\Delta L / L)}$$

$$\Delta d = 0.024\, \mu m$$

5(a)

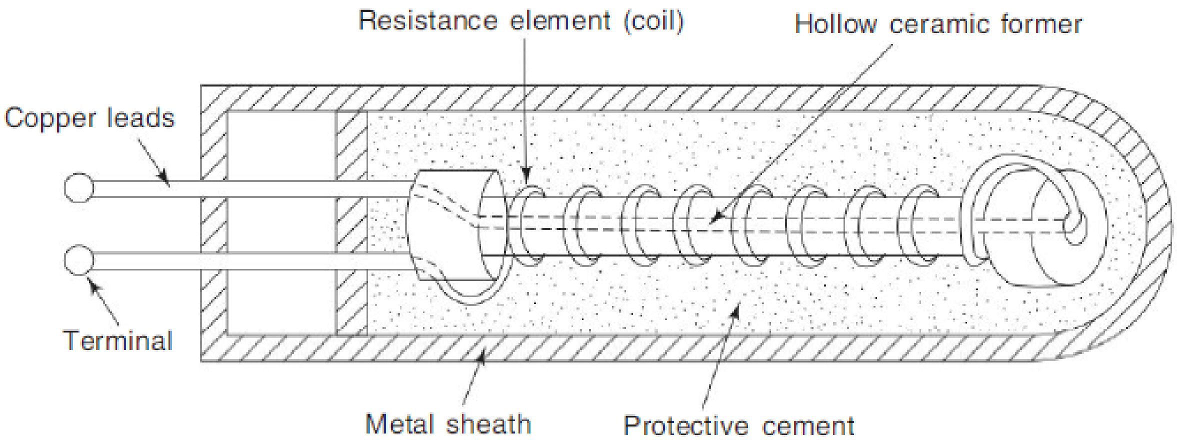


Fig : RTD

The working principle of RTD is the variation of its resistance with temperature. The metal widely used for construction of RTD is platinum.

The relation between the resistance and temperature is given by

$R = Ro\,(1 + aT + bT^2)$

where R= resistance at temperature T

R0 = resistance at 0^o C

a, b = constants

5(b)

Sol:- Using the above information,

$$138.50 = 100\left(1 + 100\alpha + 10^4\beta\right) \rightarrow (1)$$

$$175.83 = 100\left(1 + 200\alpha + 4\times10^4\beta\right) \rightarrow (2)$$

Solving eqs(1) and (2),

$$(2\times138.50 - 175.83) = 100\left[2 + 200\alpha + 2\times10^4\beta - 1 - 200\alpha - 4\times10^4\beta\right]$$

$$101.17 = 100\left(1 - 2\times10^4\beta\right)$$

$$1.0117 = 1 - 2\times10^4\beta$$

$$2\times10^4\beta = -0.0117$$

$$\beta = -5.87\times10^{-7} /^{\circ}C^2$$

Now using eq(1),

$$138.50 = 100\left[1 + 100\alpha + 10^4(-5.85\times10^{-7})\right]$$

$$= 100 + 10^4\alpha - 0.585$$

$$\alpha = 39.085\times10^{-4} /^{\circ}C$$

The nonlinear term in the resistance temperature relation is $R_0\beta t^2$.

Hence the absolute value of the nonlinearity at 100°C is

$$|R_0\beta t^2| = 100\times5.85\times10^{-7}\times10^4$$

$$= 0.585\,\Omega$$

Since the thermometer is to measure a maximum temp. of 200°C, the full scale deflection should occur at that temperature. The corresponding value of the resistance is 175.83 Ω

∴ Nonlinearity at 100°C as a percent of full scale deflection $= \frac{0.585}{175.83}\times100$

$$= 0.3327$$

6(a)

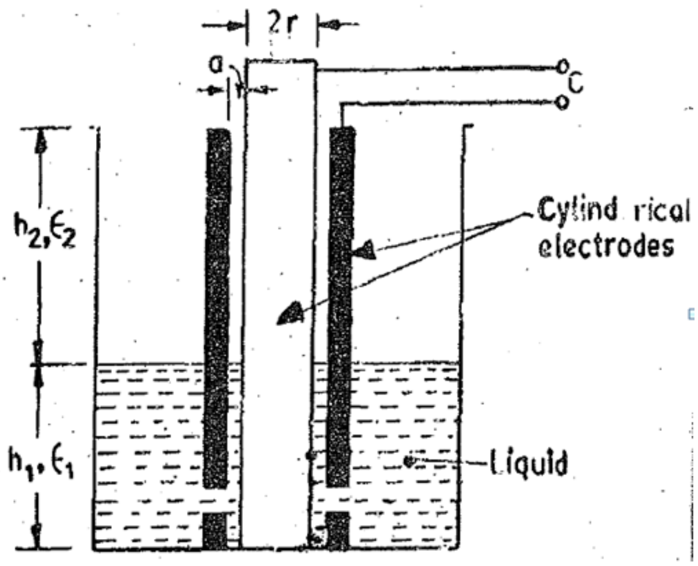


Fig : Capacitive transducer for measurement of liquid level.

Capacitive transducers using the principle of change of capacitance with change of dielectric are used for measurement of liquid level. The electrodes are two concentric cylinders and the non conducting liquid acts as the dielectric. At the lower end of the outer cylinder there are holes which allow passage of liquid. The value of capacitance for this capacitance is given by

$$C = 2 \frac{h_1 \epsilon_1 + h_2 \epsilon_2}{\log_e (1 - a/r)} \text{ F}$$

where

h1 = height of liquid
h2 = height of cylinder above liquid surface
ε1 = permittivity of the liquid
ε2 = permittivity of the gas above liquid
r = outside radius of inner cylinder
a = distance between inner and outer cylinders.

The above equation is based upon the assumptions that h > r2 and r > r2 - r1.

6(b)

Solution: Given that

Separation between plates (d) = 0.05 mm

Capacitance of a parallel plate capacitor (C) = 5×10^{-12} F

Change in capacitance due to displacement (ΔC) = 0.75×10^{-12} F

As we know

$$C = \frac{\varepsilon A}{d}$$

$$\therefore \varepsilon A = Cd = 5 \times 10^{-12} \times 0.05 \times 10^{-3} = 0.25 \times 10^{-15} F$$

$$|\Delta x = \frac{\varepsilon A}{\Delta C} = \frac{0.25 \times 10^{-15}}{0.75 \times 10^{-12}} = 0.333 mm$$

7(a)

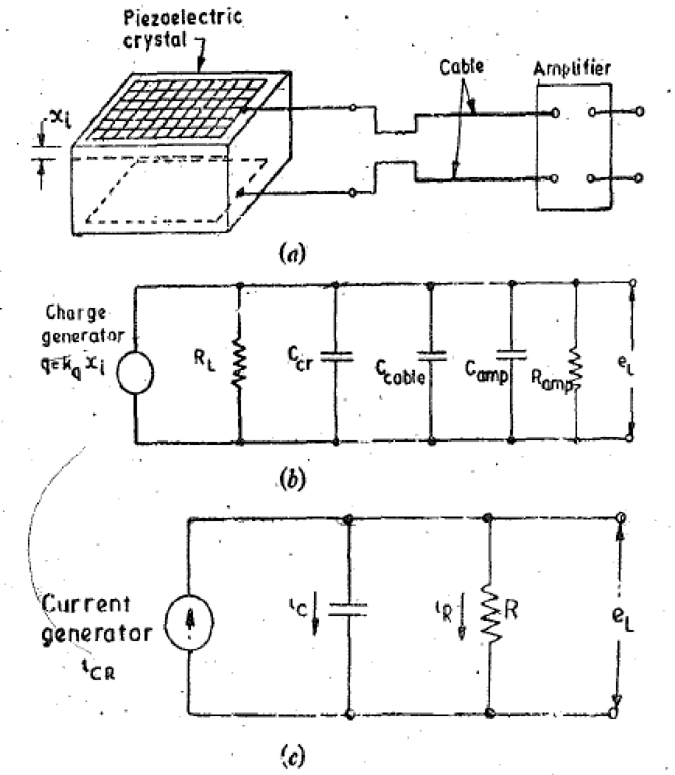


Fig : Set up of a piezoelectric transducer and its equivalent circuit.

Now $\qquad i_{CR} = i_C + i_R$

∴ Output voltage at load $e_L = e_o = \frac{1}{C}\int i_C \, dt = \frac{1}{C}\int (i_{CR} - i_R)\, dt$

or $\qquad \frac{d(e_L)}{dt} = \frac{1}{C}(i_{CR} - i_R)$

or $\qquad C\frac{d(e_L)}{dt} = i_{CR} - i_R = K_q \frac{d(x_i)}{dt} - \frac{e_L}{R}$

or $\qquad RC\frac{d(e_L)}{dt} + e_L = K_q R\frac{d(x_i)}{dt}$

$$\tau\frac{d(e_L)}{dt} + e_L = K\tau\frac{d(x_i)}{dt}$$

where $\qquad K = \text{sensitivity} = \frac{K_q}{C}$ V/m

Taking Laplace transform, we get : $(\tau s + 1)\, E_L(s) = K\tau s\, X_i(s)$

∴ Transfer function $\qquad \frac{E_L(s)}{X_i(s)} = \frac{K\tau s}{1+\tau s}$

Sinusoidal transfer function $\frac{E_L}{X_i}(j\omega) = \frac{j\omega K\tau}{1+j\omega\tau}$

The amplitude ratios is :

$$M = \left|\frac{E_L}{K X_i}(j\omega)\right| = \frac{\omega\tau}{\sqrt{1+(\omega^2\tau^2)}} = \frac{1}{\sqrt{1+(1/\omega\tau)^2}}$$

The phase shift $\phi = \pi/2 - \tan^{-1}\omega\tau$ rad.

At high frequencies $\omega \gg 1$ $\qquad$ ∴ $M = 1$ and $\phi = 0$

Hence high frequency sensitivity is : $K = \frac{e_L}{x_i}$

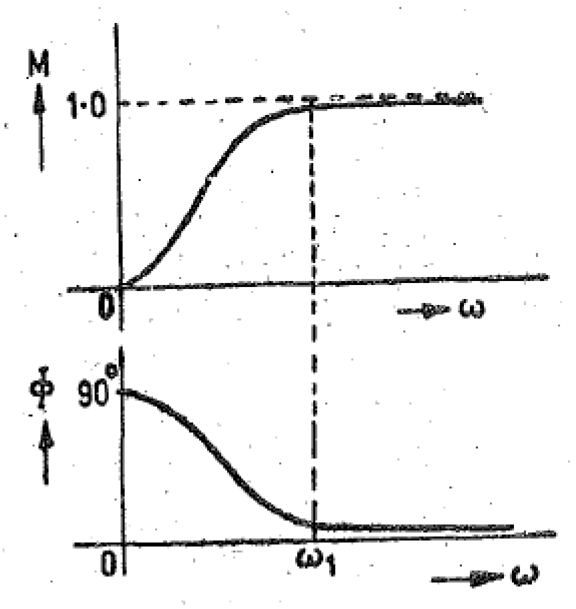


Fig : Frequency response of piezoelectric transducer

7(b)

Given E_0 = 100 V, g = 0.055 V m / N , t = 1.5 mm, A = 5mm × 5mm

$P = E_0 / g\, t = 1.2\ MN/m^2$

F = P A = 30 N

8(a)

Types of configurations of Optical Fibre sensors :

There are two types

(a) Extrinsic sensors (or incoherent sensors)

(b) Intrinsisc sensors (or coherent sensors)

The emitter, which may be a light emitting diode or a laser source, emits the light rays through the fibre, which get modulated due to the outer signal, which is to be measured. The output fibre is connected to the detector, which converts the optical energy into electrical energy.

These detectors work on the principle of creation of an electron - hole pair in semiconductors or the release of electrons from the cathode of the photomultiplier tube.

In the case of the extrinsic sensor, as in fig(a) the intensity modulation of light takes place outside the fibre, which in the case of fig (b) viz, intrinsic sensor, it takes place within the fibre.

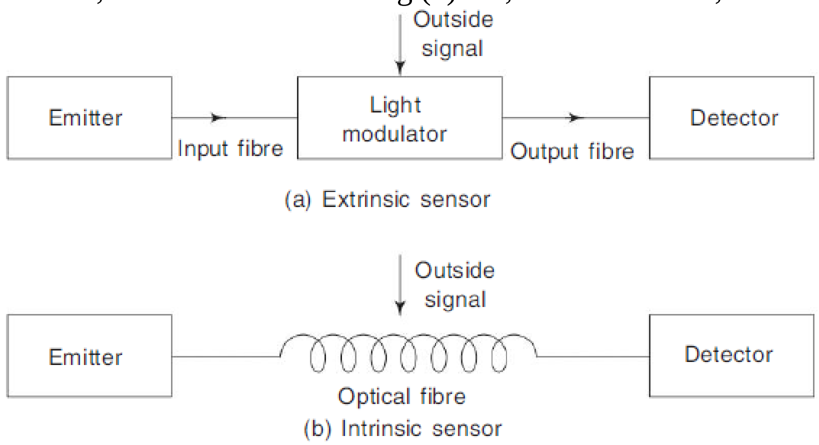


Fig : types of optical fibre sensor configurations

Examples of two types of sensors are given in the following fig

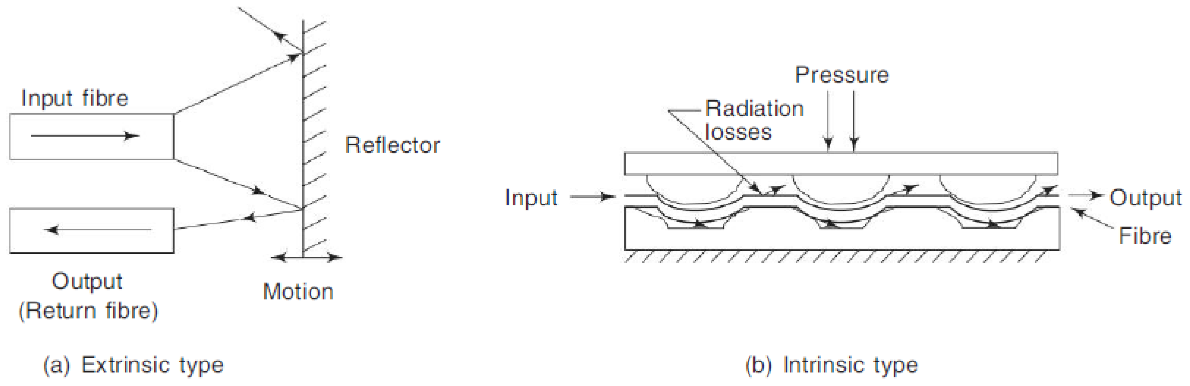


Fig : Examples of extrinsic and intrinsic type sensors

Fig(a) shows an extrinsic or external intensity modulator type of sensor in which the position of the reflector due to motion to be measured may change, thus changing the light intensity in the output fibre. This is detected by a detector.

In fig (b), the fibre bending due to the pressure, which is the input variable, to be measured, induces radiation lossses, changing the intensity at the output. This happens within the fibre itself and hence the configuration is called as intrinsic type. This causes radiation of light even at small deformation and is also called micro-bend sensor. In this type of sensor configuration, apart from the intensity modulator, there may be phase or frequency modulation, which after detection may be used for several applications.

8(b)

The following figure shows the configuration of a fibre optic temperature sensor.

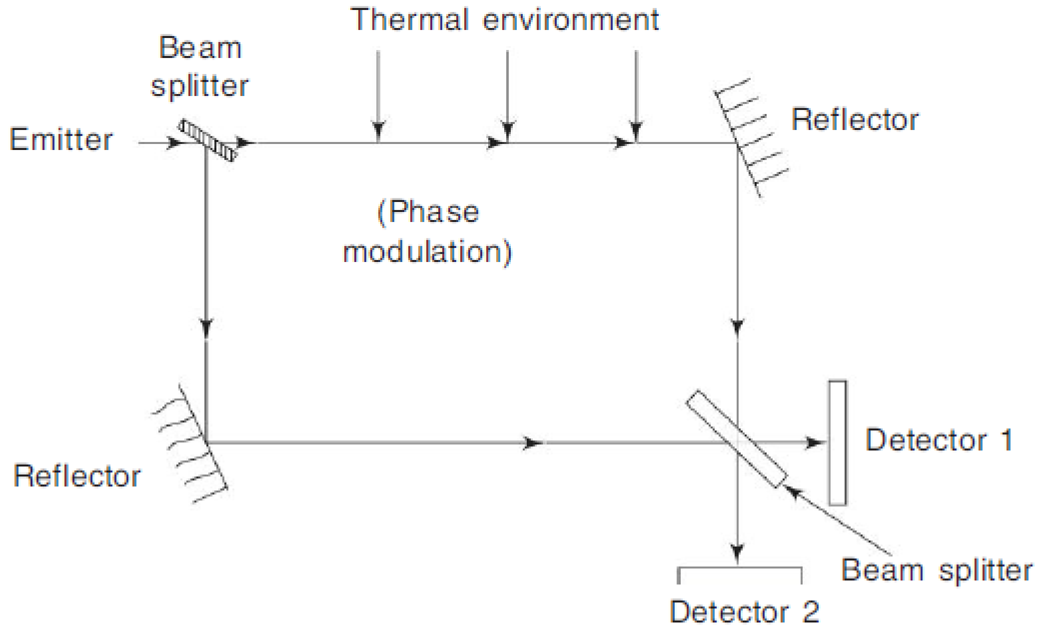
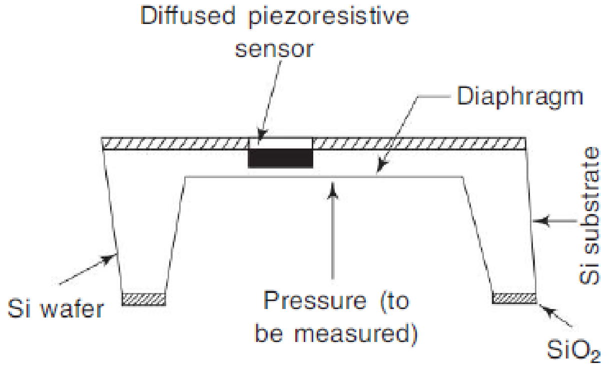


Fig : A typical fibre optic temperature sensor

It is seen that the phase of light gets changed due to change in the length of the fibre as a result of application of longitudinal strain due to thermal expansion. The change in phase is converted to intensity variations using Mach Zehnder interferometer as shown in the above figure. The intensities at the two detectors are seen to be proportional to $1 \pm \cos \delta$, when δ is the phase change due to phase modulation. The value of δ for glass fibre is about 100 rad /0C of length and thus the device is highly sensitive. This type of device is of intrinsic or of coherent type.

9(a)

The following figure shows a silicon type micro pressure transducer using a diaphragm integral with the silicon substrate. Then a piezo resistive sensor is diffused at the appropriate locations so that the strain and resistance changes are sufficient enough to produce an output from the bridge



formed by the sensors.

Fig : Diaphragm type silicon micro pressure transducer

9(b)

APPLICATIONS OF INFRA RED RADIATION

Radiation thermometers

Compared to various other methods of temperature measurement, radiation thermometers have following features

a) Measurement without direct contact with the object

b) Faster response

c) Easy pattern measurements.

Detectors used for radiation thermometers depend upon the temperature and material of the object to be measured. For example, glass have peak wavelength near 5 µm and hence, detectors sensitive to these wavelengths are used.

Flame monitors

Flame monitors are used for detecting light emitted from the flames and to monitor how the flames are burning. Light emitted from flames extend from UV to IR region. PbS, PbSe, Two-color detector, pyroelectric detector, etc. are some of the commonly employed detector used in flame monitors.

Moisture analyzers

These analyzers use those wavelengths which are absorbed by moisture in IR region, i.e., 1.1 µm, 1.4 µm, 1.9 µm, and 2.7 µm. Objects are irradiated with light having these wavelengths and also with reference wavelengths. Lights reflected from the objects depend upon the moisture content and is detected by analyzer to measure moisture (ratio of reflected light at these wavelengths to the reflected light at reference wavelength). InGaAs PIN photodiodes, PbS photoconductive detectors are employed in moisture analyzers.

Gas Analyzers

Gas analyzers use absorption characteristics of gases in IR region to measure gas density. Two types of methods are used

a) Dispersive: Emitted light is spectroscopically divided and their absorption characteristics are used to analyze the gas ingredients and the sample quantity.

b) Nondispersive: It is more commonly used; it uses absorption characteristics without dividing the emitted light. Nondispersive types use discrete optical bandpass filters, similar to sunglasses that are used for eye protection to filter out unwanted UV radiation. This type of configuration is commonly referred to as nondispersive infrared (NDIR).

Dispersive or ingredient analyzer is used for carbonated drinks, whereas nondispersive analyzer is used in most of the commercial IR instruments, for automobile exhaust gases fuel leakages, etc.

IR Imaging devices

This is one of the prime applications of IR waves, primarily by virtue of its property that it is not visible. It is used for thermal imagers, night vision devices, etc.

Water, rocks, soil, vegetation, the atmosphere, and human tissue all features emit IR radiation. Thermal infrared detectors measure these radiations in IR range and map the spatial temperature distributions of the object/area on an image. Thermal imagers usually composed of In:Sb (indium antimonide), Gd:Hg (mercury-doped germanium), Hg:Cd:Te (mercury-cadmium-telluride)

The detectors are cooled to low temperatures using liquid helium or liquid nitrogen. Cooling the detectors insures that the radiant energy (photons) recorded by the detectors comes from the terrain and not from the ambient temperature of objects within the scanner itself.

Remote sensing

As all objects emit light, the measurement of each wavelength of this emitted light provides lots of specific information about the object. This is precisely what is done in remote sensing to obtain information like temperature of land and sea water, gas concentration of atmosphere, etc.

Missile Guidance

Missiles use passive infrared guidance system wherein Infrared energy emitted by a target is used for homing. Infrared seekers are used in missiles for this purpose.

Optical Power meters

For long distance optical communication systems, IR beams in the wavelength region from 1.3 to 1.5 are employed. Optical power meters are used to measure light intensity, optical fiber transmission loss, laser power, etc. in applications like optical fiber communications, lasers, etc. They use InGaAs PIN photodiodes, etc. for optical power measurement.

Sorting devices

These devices use the inherent property of absorption of some IR wavelengths to sort agricultural crops from stones, clods, etc. Such devices use InGaAs PIN photodiodes, PbS detectors.

Human body detection

Such devices are used for detection of a person. Typical applications are intrusion detection, autolight switches, etc. Intrusion alarm devices sense the temperature of a person and rings alarm if sensed temperature crosses some threshold. Such devices also employ optical filters to make use of a specific window (appropriate for human body) of electromagnetic spectrum and to protect it from external disturbances.

Spectrophotometers(FT-IR)

Infrared detectors are at the heart of Fourier Transform IR. In FTIR spectrophotometry, interference signal from double beam interferometer undergoes Fourier transformation by which signal is decomposed into a spectrum.

LD Monitors

The output level and emission wavelength of a Laser Diode varies with the temperature. For the purpose of automatic stabilization of Laser Diode emission wavelength, Laser diode power is monitored using InGaAs PIN photodiodes, InAs, InSb detectors, etc